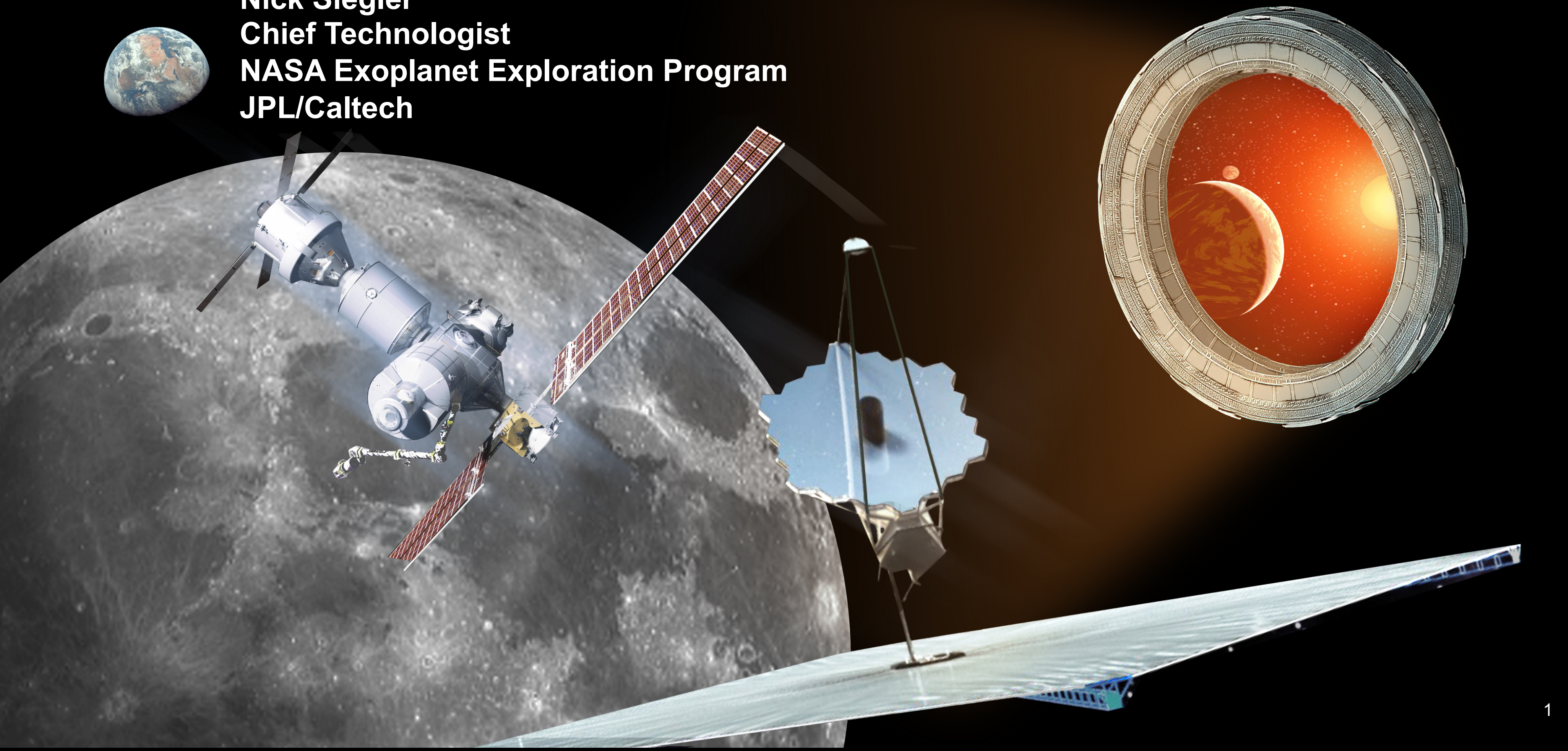
# Building the Future:
# In-Space Assembled Telescopes (iSAT) Study
## Overview and Status

Nick Siegler
Chief Technologist
NASA Exoplanet Exploration Program
JPL/Caltech





Landscape Conference
April 2, 2019

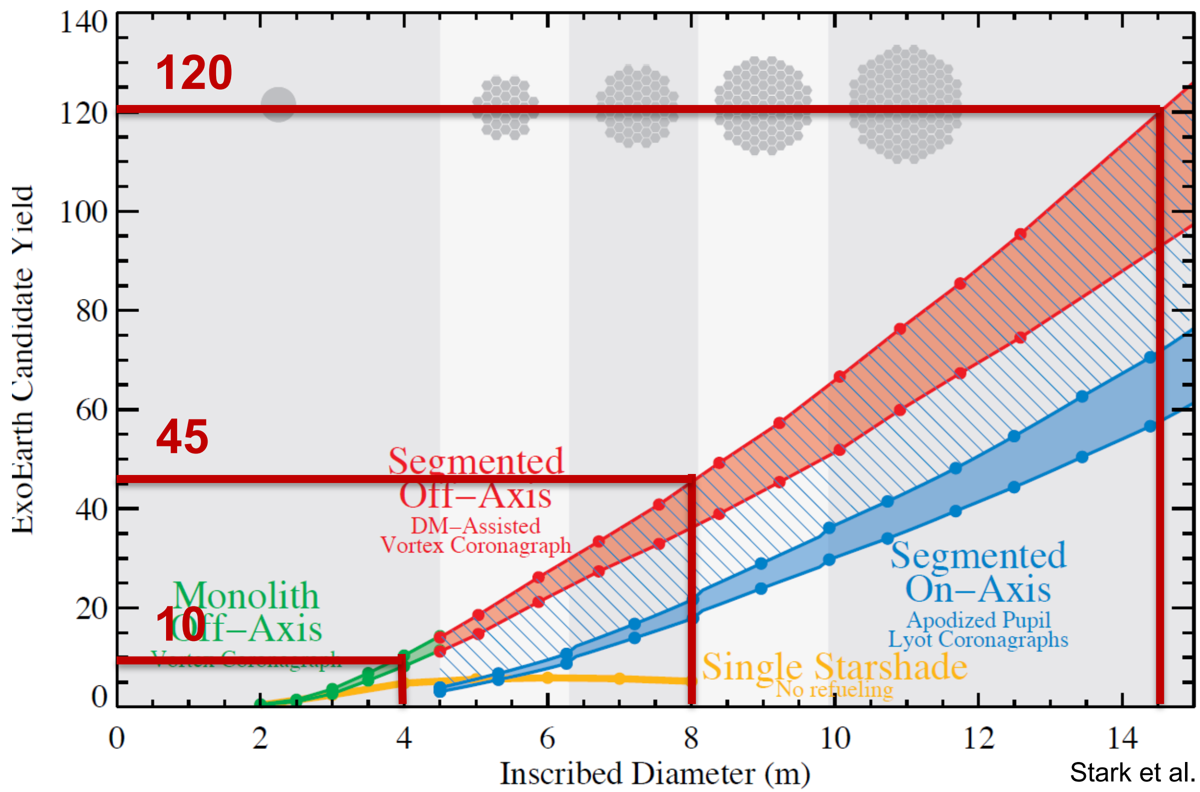
David Charbonneau (Harvard)
Scott Gaudi (Ohio State University)

**National Academies Exoplanet Science Strategy Report Released 9/5/18:**

***Recommendation #1:***

*NASA should lead a large strategic direct imaging mission capable of measuring the reflected-light spectra of temperate terrestrial planets orbiting Sun-like stars.*

**Predictive models conclude need 8 m-class telescopes to collect robust results**




Stark et al. (2019)

Thomas Zurbuchen
Associate Administrator
NASA Science Mission
Directorate

**"I love exoplanet science and the search for life. But why do these large telescopes have to cost so much?"**

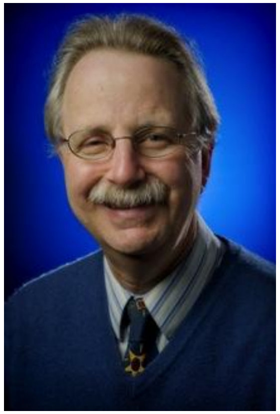
# In-Space Assembly and Servicing Workshop at NASA GSFC
# November 2017


**70+ participants from government, industry, and academia**

✓ 1. **Commission a design study to understand how large-aperture telescopes could be assembled and serviced in space**

✓ 2. **Provide input to the 2020 Decadal Survey about iSA as a potential implementation approach for future large apertures.**

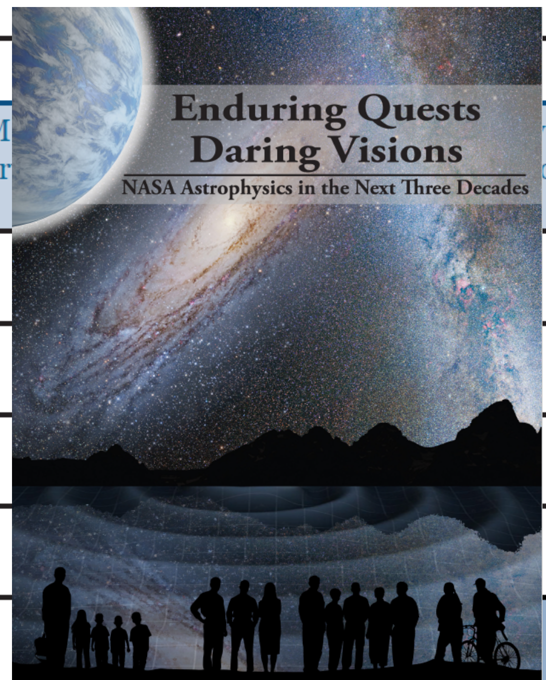
# Study Objective and Deliverables



Dr. Paul Hertz
Director
Astrophysics Division
NASA Headquarters

- **Study Objective:**
  – ***"When is it worth assembling space telescopes in space rather than building them on the Earth and deploying them autonomously from single launch vehicles?"***

| | | | | Visionary Era | | | |
|---|---|---|---|---|---|---|---|
| | GW Surveyor | CM Sur | or | GW Mapper | Cosmic Dawn Mapper | ExoEarth Mapper | Black Hole Mapper |
| Formation flying | | | | | | | |
| Interferometry: precision metrology | | | | | | | |
| X-ray interferometry | | | | | | | |
| High-contrast imaging techniques | | | | | | | |
| Optics deployment and assembly | | | | | | | |




4. A list of technology gaps and technologies that may enable in-space assembly

# Study Participants

| Name | Institution | Expertise |
|---|---|---|
| 1. Ali Azizi | NASA JPL | Metrology |
| 2. Gary Matthews | Consultant | Mirror Segments |
| 3. Larry Dewell | Lockheed | Pointing/Stability/Control |
| 4. Oscar Salazar | NASA JPL | Pointing/Stability/Control |
| 5. Phil Stahl | NASA MSFC | Telescope Architecture |
| 6. Jon Arenberg | Northrop | T |
| 7. Doug McGuffey | NASA GSFC | S |
| 8. Kim Aaron | NASA JPL | S |
| 9. Bill Doggett | NASA LaRC | R |
| 10. Al Tadros | SSL | R |
| 11. Bob Hellekson | Orbital-ATK | T |
| 12. Gordon Roesler | DARPA | R |
| 13. Eric Mamajek | NASA ExEP | A |
| 14. Shanti Rao | NASA JPL | C |
| 15. Ray Ohl | NASA GSFC | C |
| 16. Sergio Pellegrino | Caltech | T |
| 17. Tere Smith | NASA JPL | I&T |
| 18. Paul Backes | NASA JPL | Robotics |
| 19. Jim Breckinridge | UA | |
| 20. Allison Barto | Ba | |
| 21. Joe Parrish | DA | |
| 22. Dave Redding | NA | |
| 23. David Stubbs | Lo | s/Design |
| 24. John Dorsey | NA | s |
| 25. Jeff Sokol | Ba | |
| 26. Brendan Crill | NA | tors |
| 27. Dave Miller | MI | |
| 28. Atif Qureshi | SS | ngineerin |
| 29. Jason Tumlinson | ST | |
| 30. Carlton Peters | NA | |
| 31. Paul Lightsey | Ba | g |
| 32. Kim Mehalick | NA | &T |
| 33. Bo Naasz | NA | g |
| 34. Eric Sunada | NASA JPL | Thermal |
| 35. Keith Havey | Harris | Telescopes |

| | | |
|---|---|---|
| 36. Lynn Allen | Harris | Optics |
| 37. Ben Reed | NASA GSFC | Robotic Servicing |
| 38. Scott Knight | Ball | Optics |
| 39. Jason Hermann | Honeybee | Robotics |
| 40. John Lymer | SSL | Robotics |
| 41. Glen Henshaw | NRL | Robotics |
| 42. Gordon Roesler | ex-DARPA | Robotic Assembly |
| 43. Rudra Mukherjee | NASA JPL | Robotics |
| 44. Mike Renner | DARPA | Robotics |
| | Orbital-ATK | Robotics/Gateway |
| | NASA JSC | Robotics |
| chen | NASA JSC | Robotics |
| | MIT | System Assembly |
| | Sensor Co | Structures |
| | NASA STMD | Structures |
| | LMC | Gateway |
| ies | NASA LaRC | Systems Eng |
| man | Boeing | Gateway |
| | NASA GSFC | Orbital Dynamicist |
| 55. Ryan Whitley | NASA JSC | Orbital Dynamicist |
| 56. Greg Lange | NASA JSC | RPO |
| | NASA OCT | Programmatic |
| | NASA LaRC | Programmatic |
| | ex-NASA | Astronaut |
| | LMC | Programmatic |
| | NRO | Programmatic |
| | Boeing | Programmatic |
| | USAF | Programmatic |
| | NRL | Programmatic |
| | KSC | Launch Vehicles |
| | OSU | Astrophysicist |
| | Made in Space | Fabrication |
| e | NASA GSFC | Astrophysicist |
| | Made in Space | Fabrication |
| 70. Bobby Biggs | LMC | Fabrication |
| 71. Alex Ignatiev | U Houston | Coatings |
| 72. Rob Hoyt | Tethers | Fabrication |
| 73. Scott Rohrbach | NASA GSFC | Scattered Light |

- **> 80 individuals**
- **6 NASA Centers**
- **14 private companies**
- **4 gov't agencies**
- **5 universities**

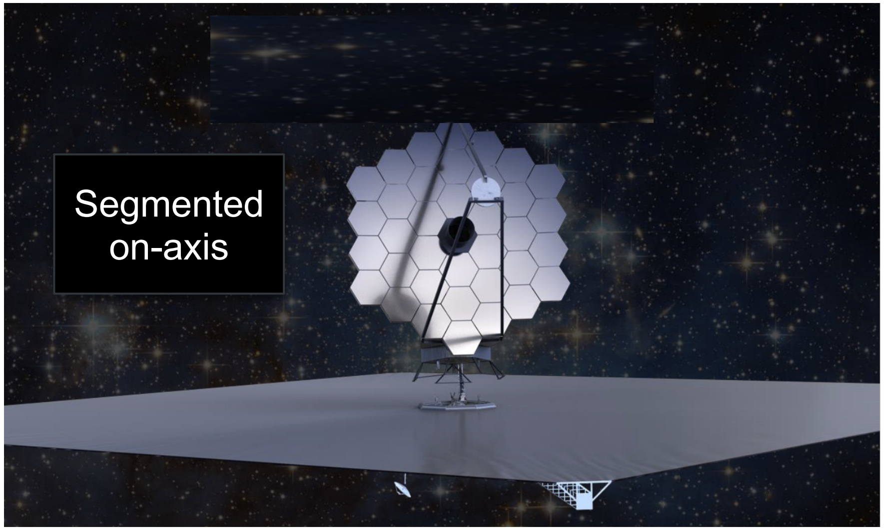
- **Lockheed**
- **Ball**
- **Orbital-ATK**
- **NGAS**
- **SSL**
- **Tethers Unlimited**

- **Harris**
- **Made in Space**
- **Honeybee**
- **several consultants**

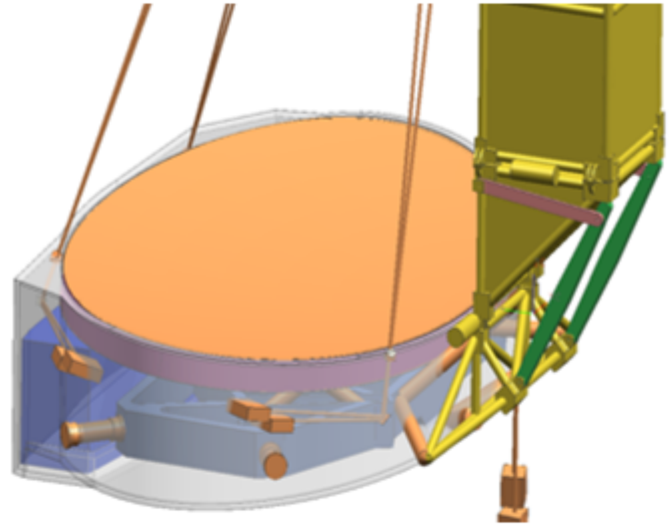
# Study Assumptions

1. **Filled-aperture, non-cryogenic telescope operating at UV/V/NIR assemblable in space**
   – *Four sizes between 5 – 20 m*
2. **The Observatory must provide the stability requirements associated with coronagraphy of exo-planets**
3. **Operational destination is Sun-Earth L2**
4. **Use of 5-m-class LV fairings**
5. **Select one reference concept to study**
   – where the team could dig deeper looking for feasibility issues and technology needs.
   – Not a down select, not a recommendation

# Telescope Concepts Considered

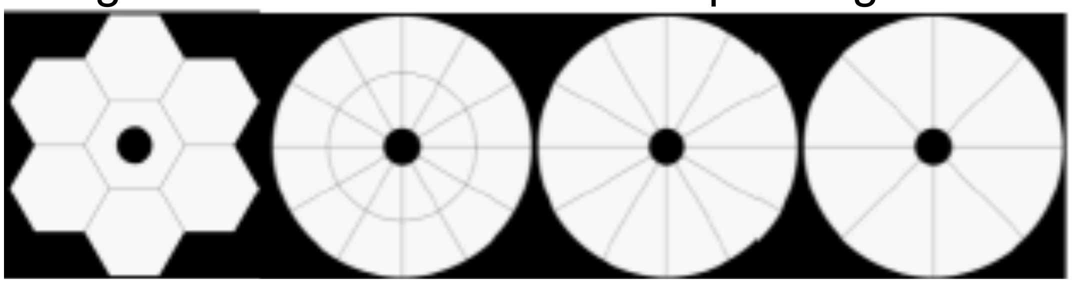



Elliptical, off-axis

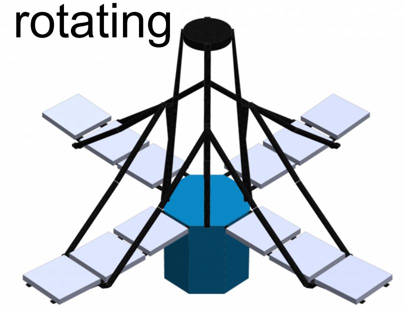


5 m segments

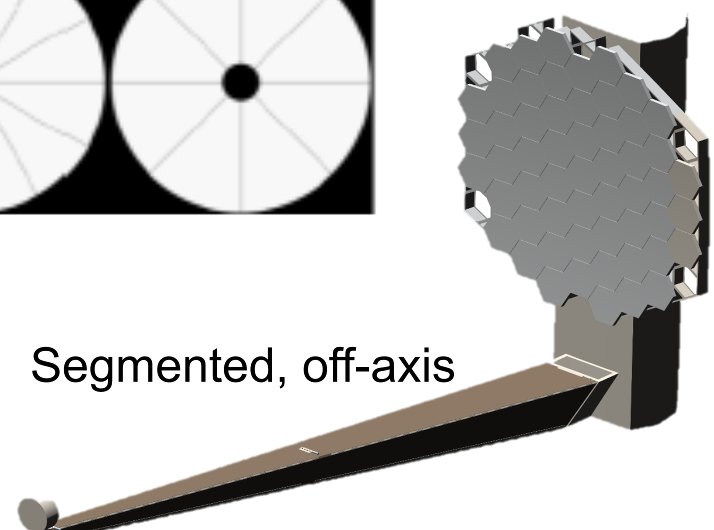
Pie-shaped segments



Sparse, rotating

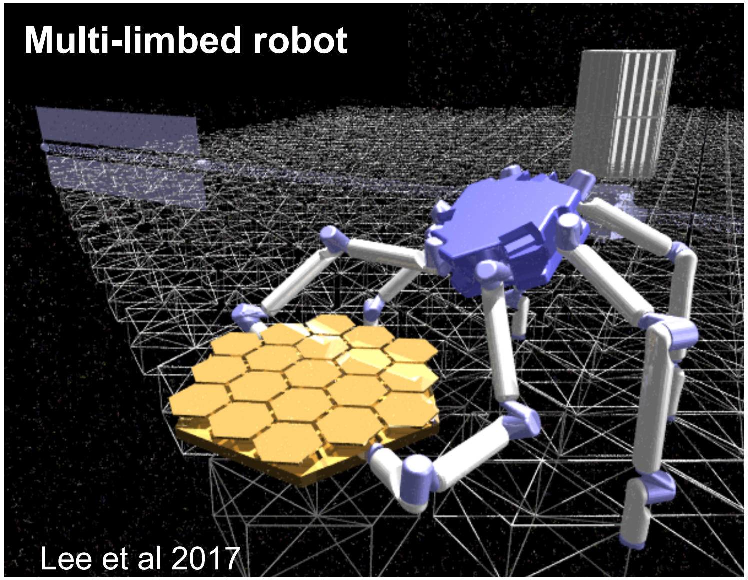


Segmented, off-axis

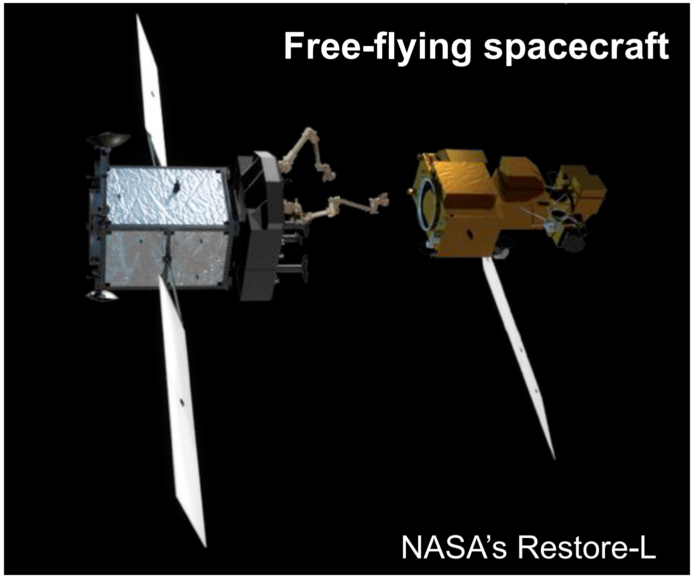


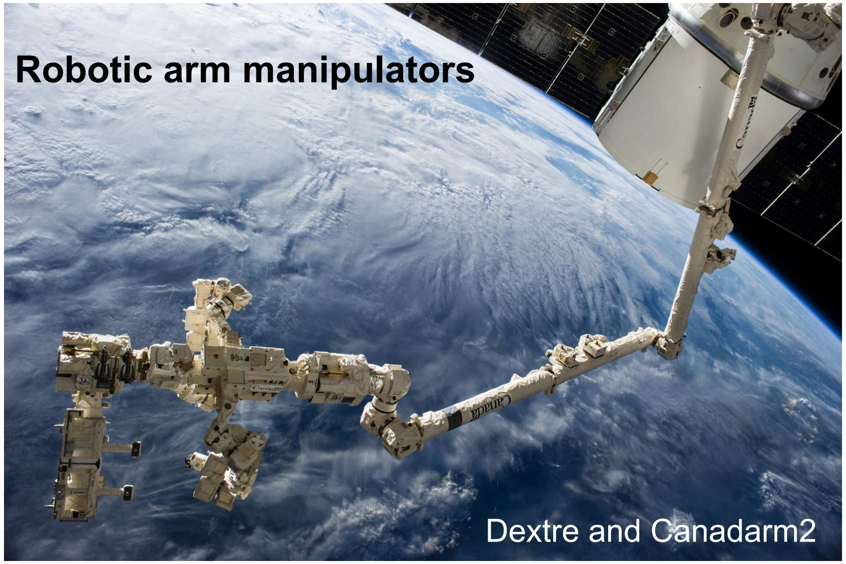
# Robot Concepts Considered

Supervised Autonomous Robotic Assembly

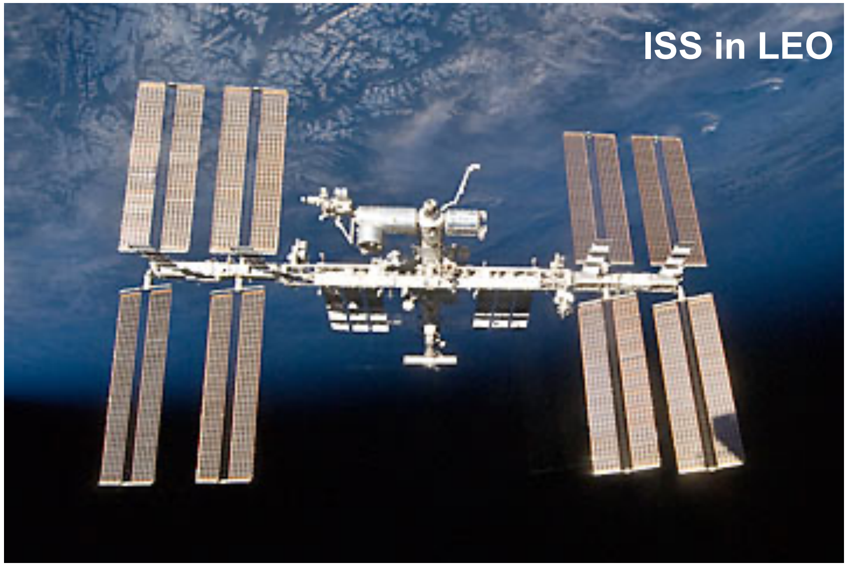






# Assembly Platforms Considered



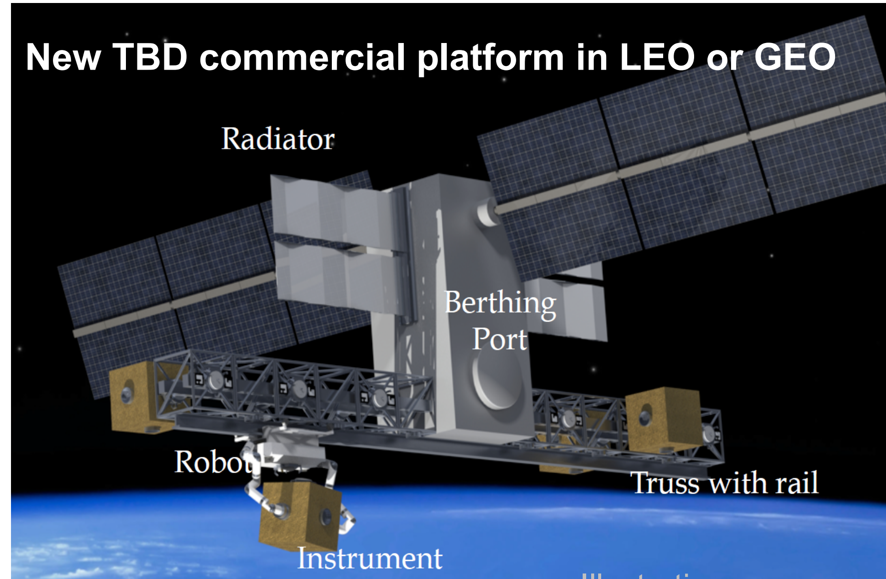
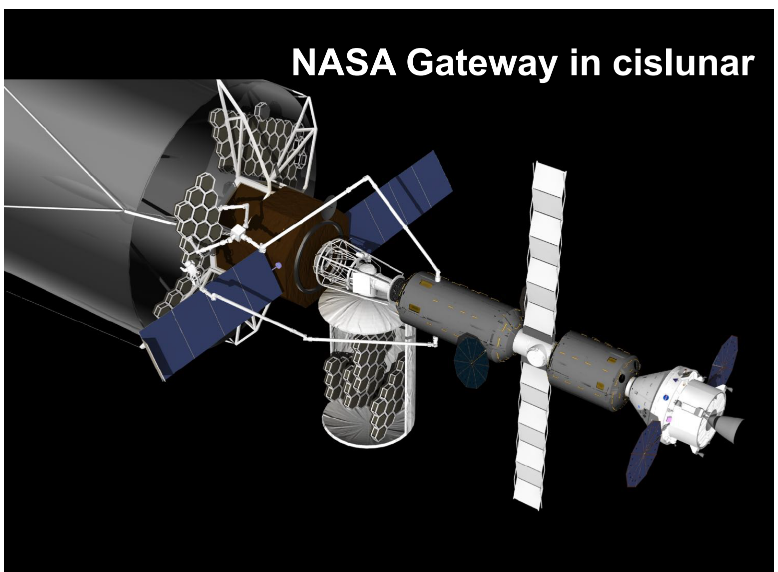
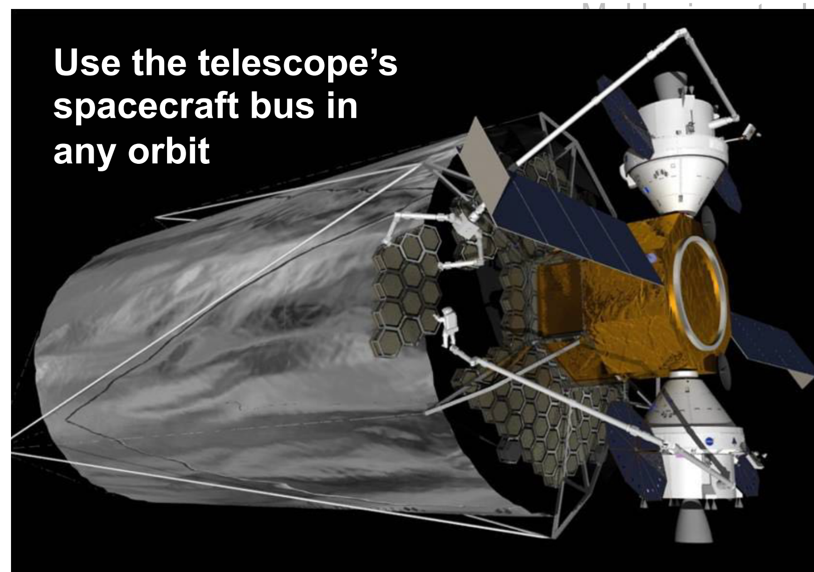




Illustration:
Rudranarayan
2016



# Many 5 m-Class Fairing Rockets to Choose From

Existing; competition drives down cost and mitigates schedule risk

**ULA's Delta IV Heavy**

Photo: United Launch Alliance

**ULA's Atlas V**

Photo: United Launch Alliance

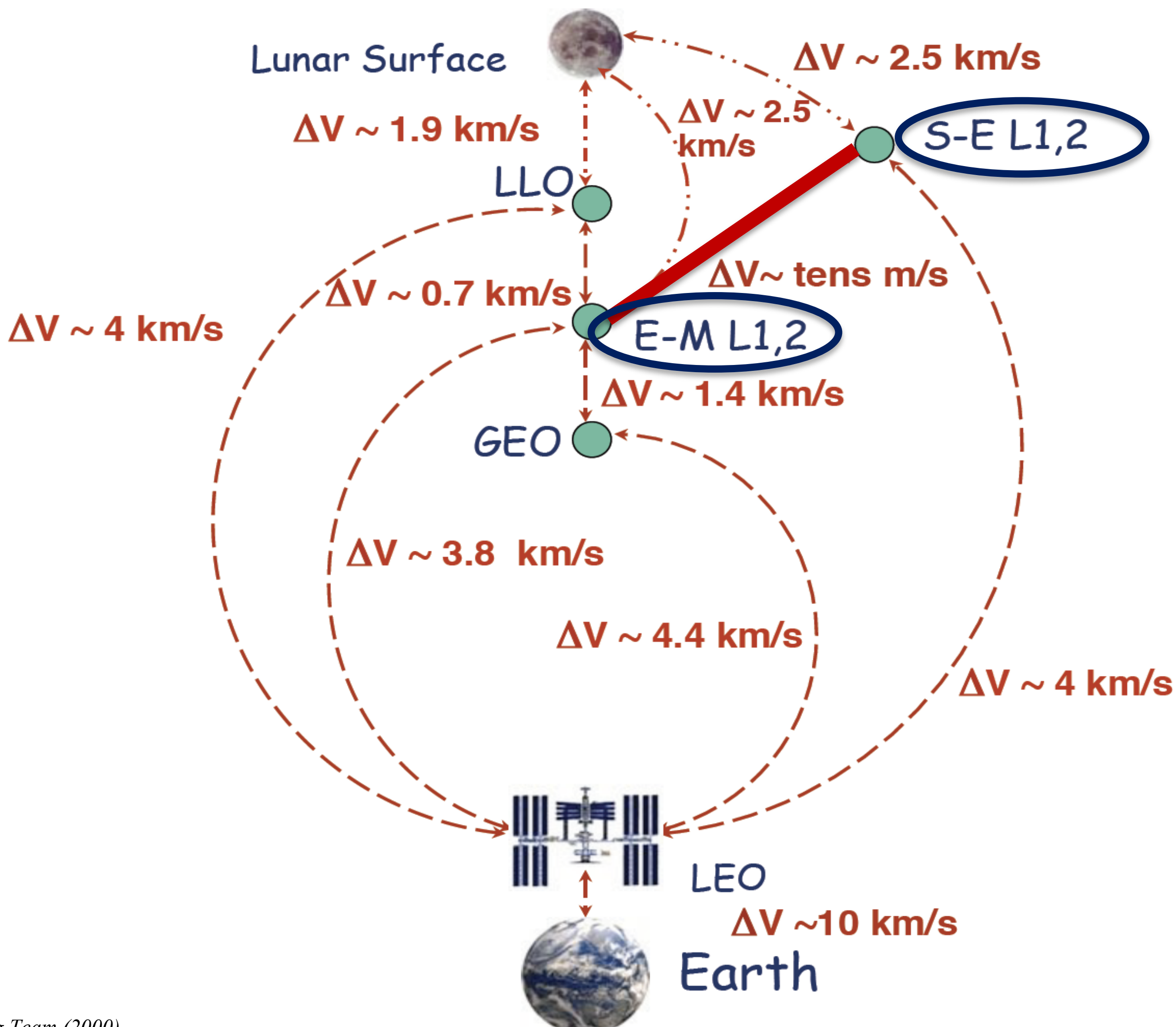
**SpaceX's Falcon Heavy**

Photo: SpaceX

**CNES' Ariane V**

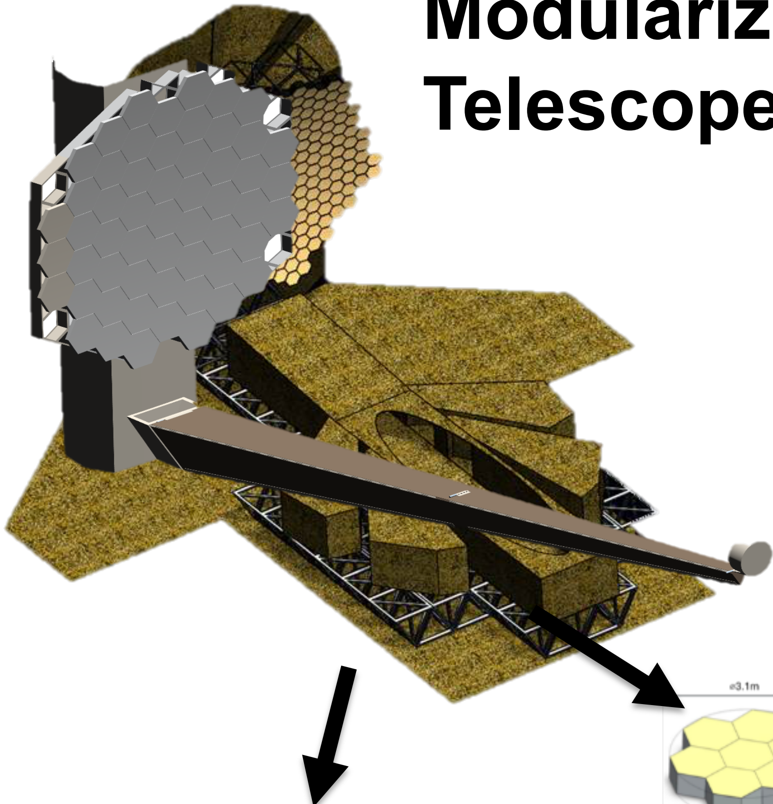
Photo: CNES

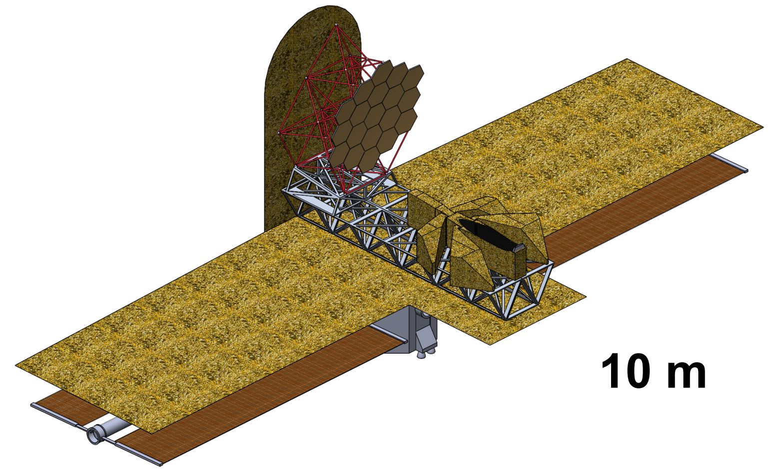
# Orbits Considered



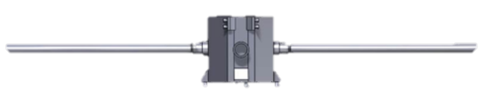

*NASA's Decade Planning Team (2000)*

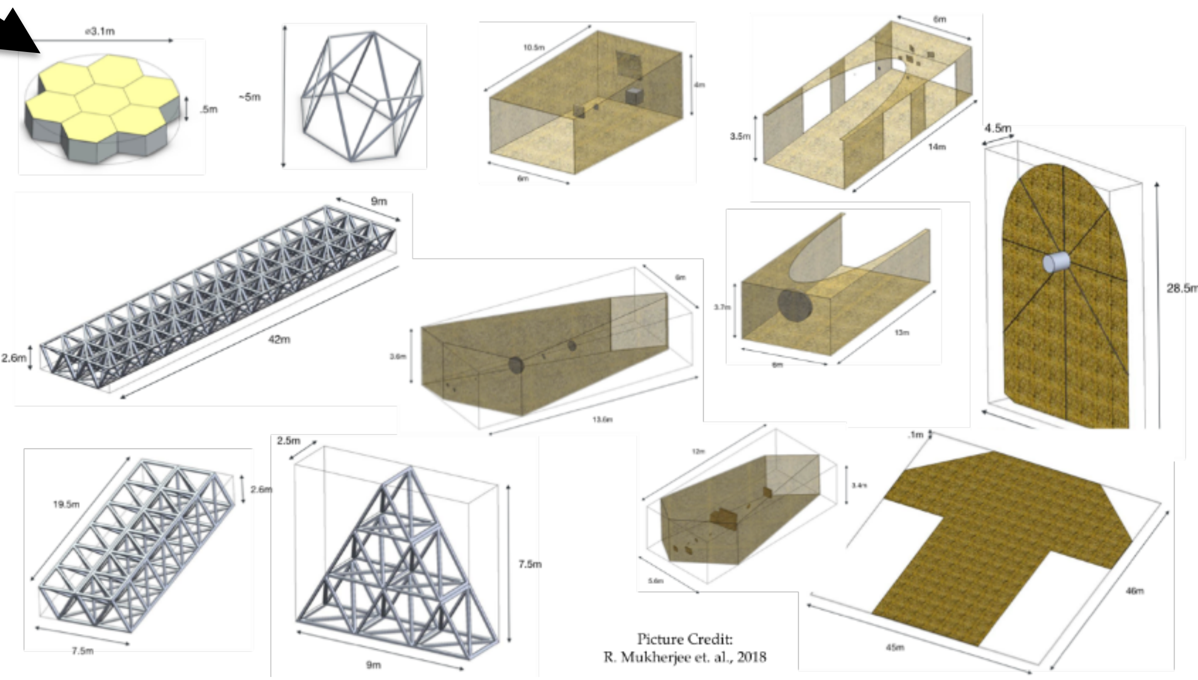
# Modularization of a 20 m Space Telescope





10 m

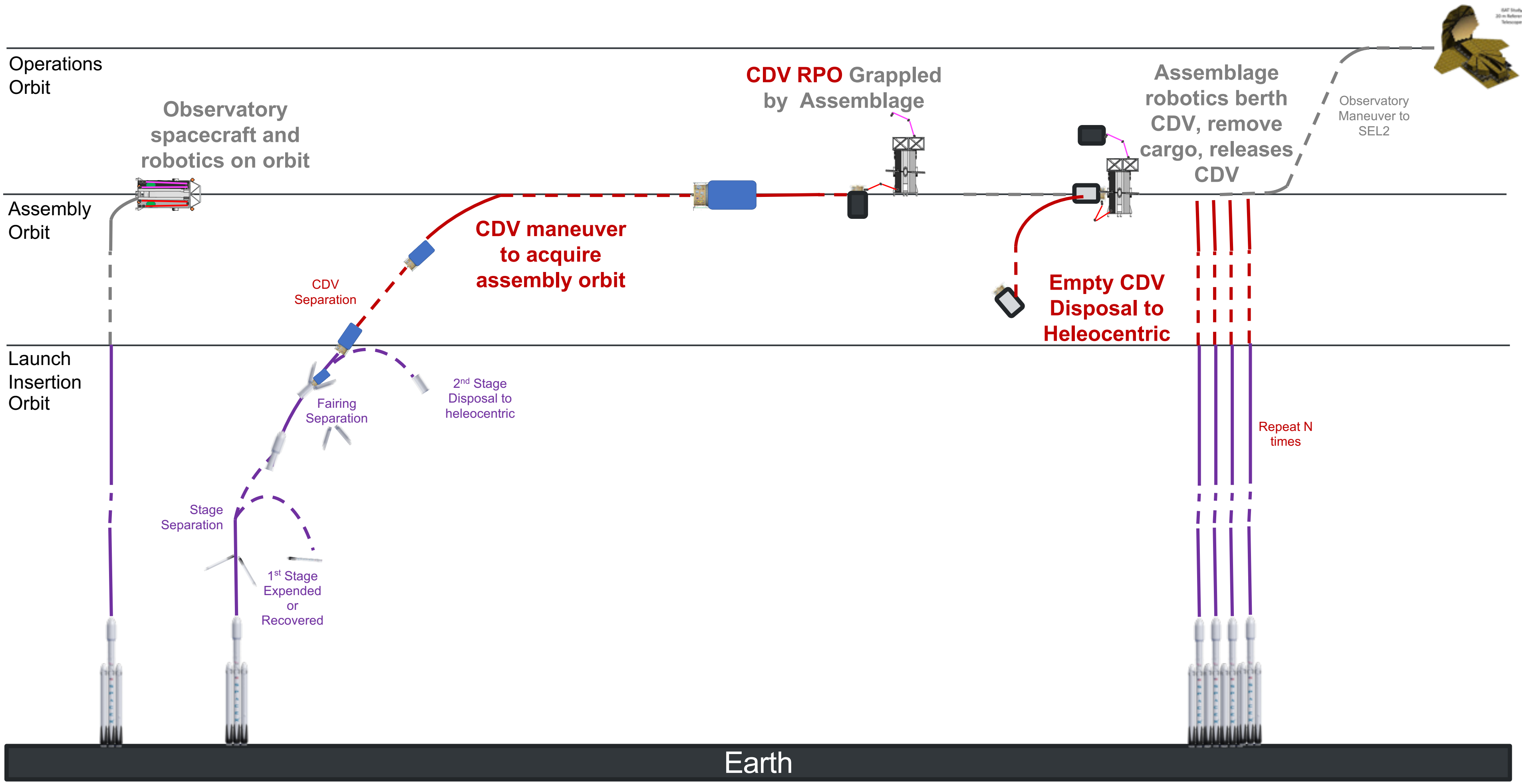




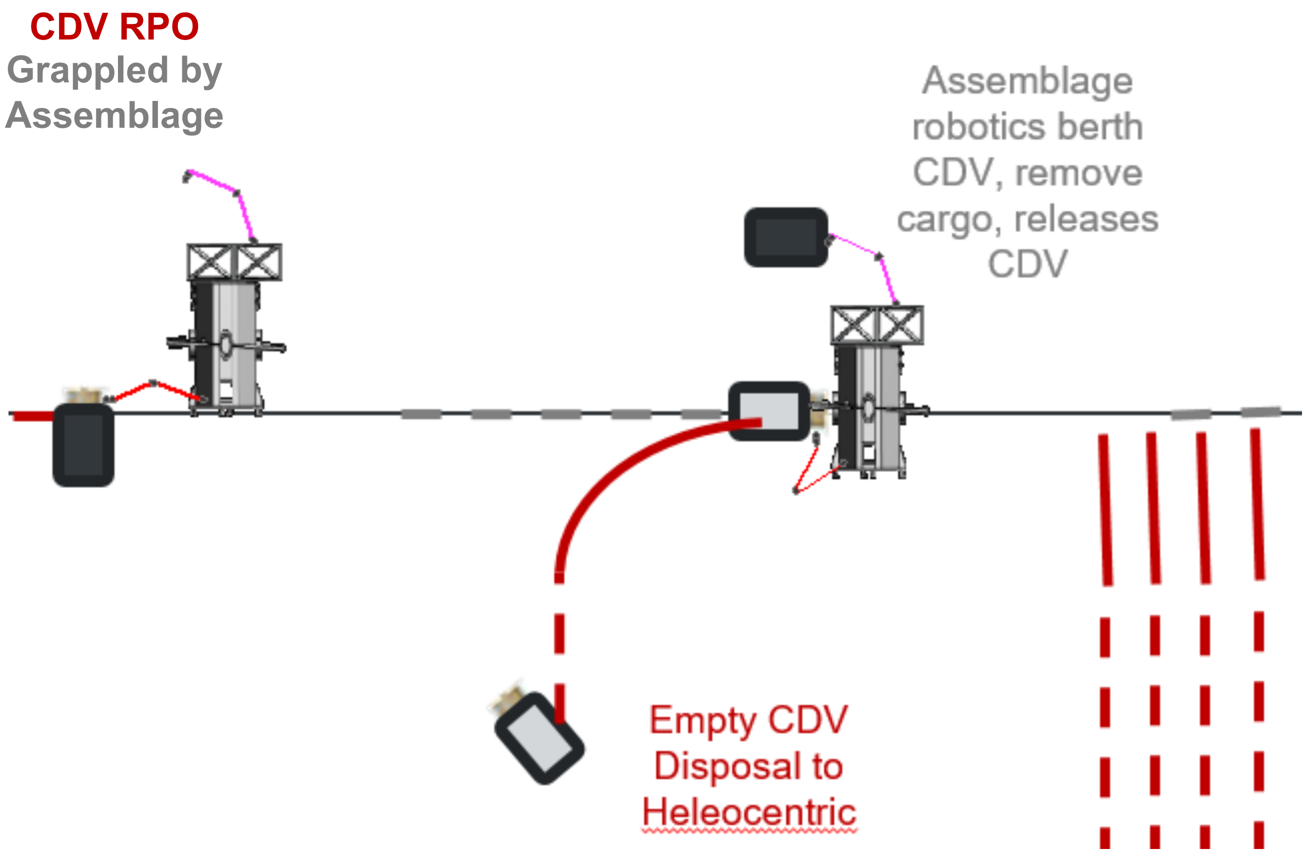

Picture Credit:
R. Mukherjee et. al., 2018

# Delivery ConOps

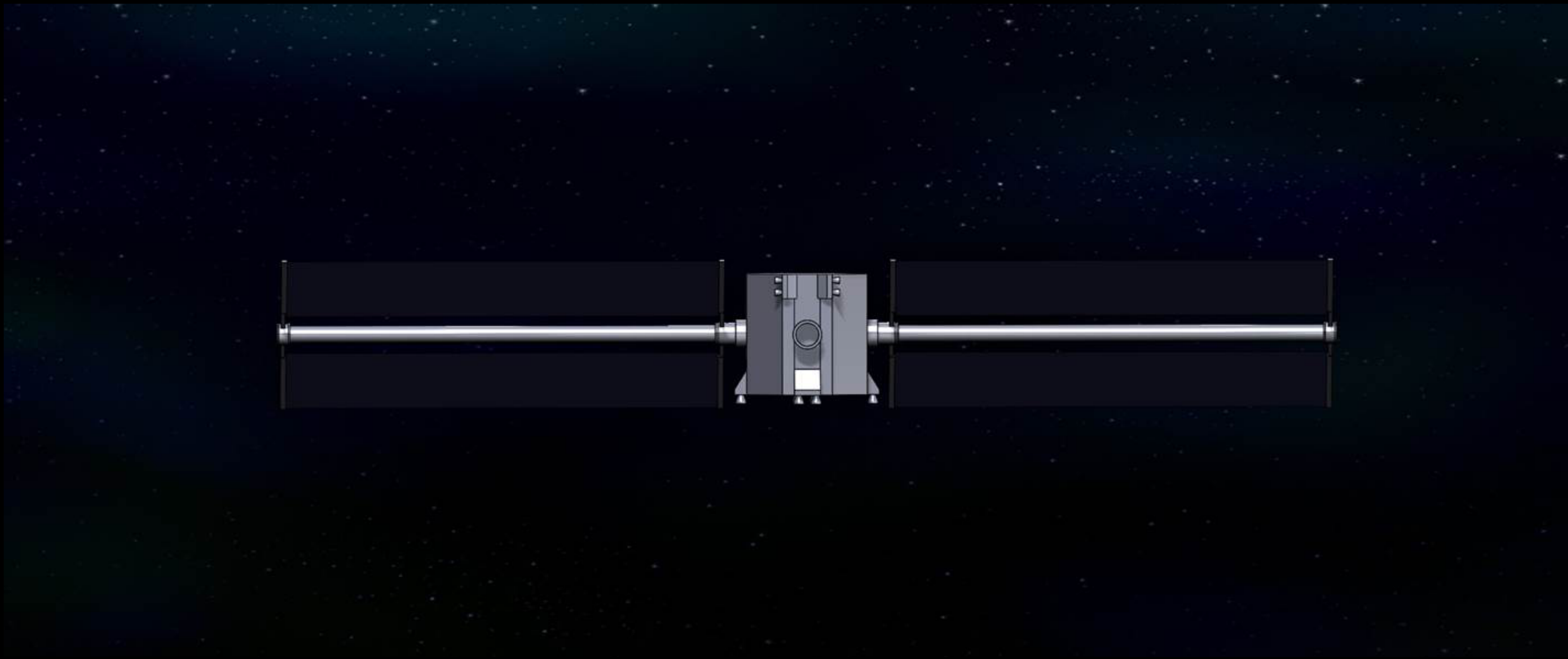
## Disposable Cargo Delivery Vehicle (CDV)



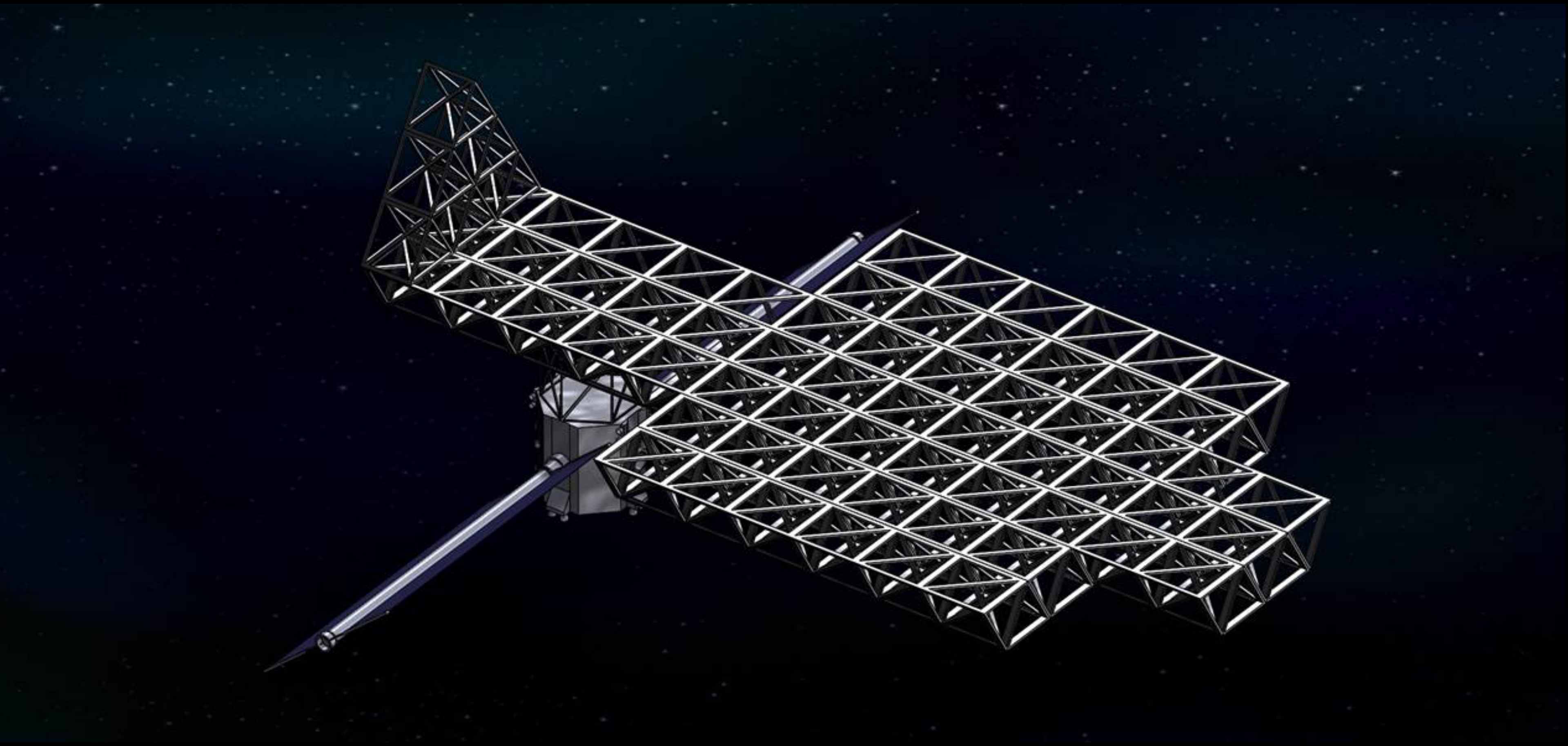
# Delivery Via Disposable Cargo Delivery Vehicle

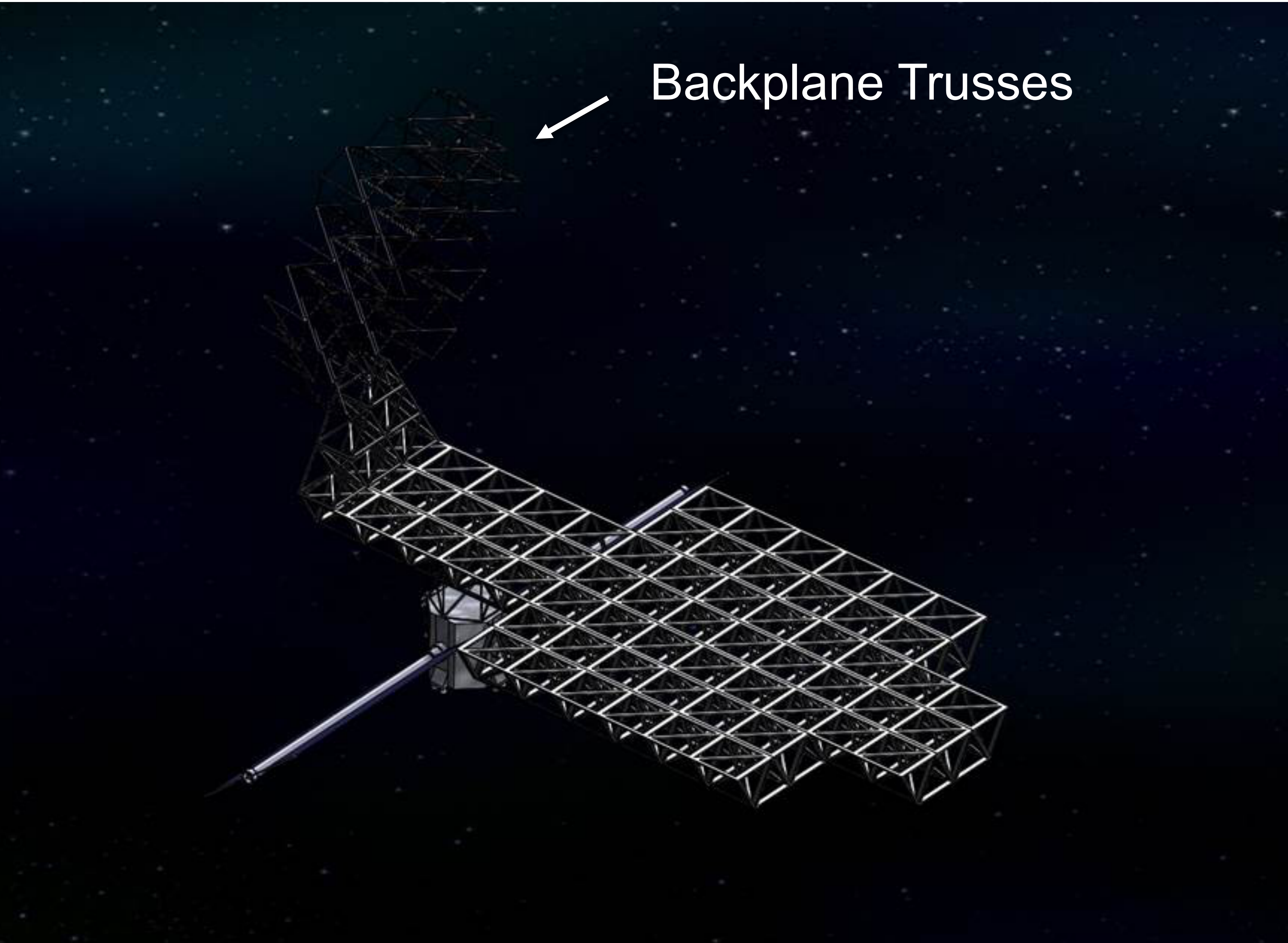


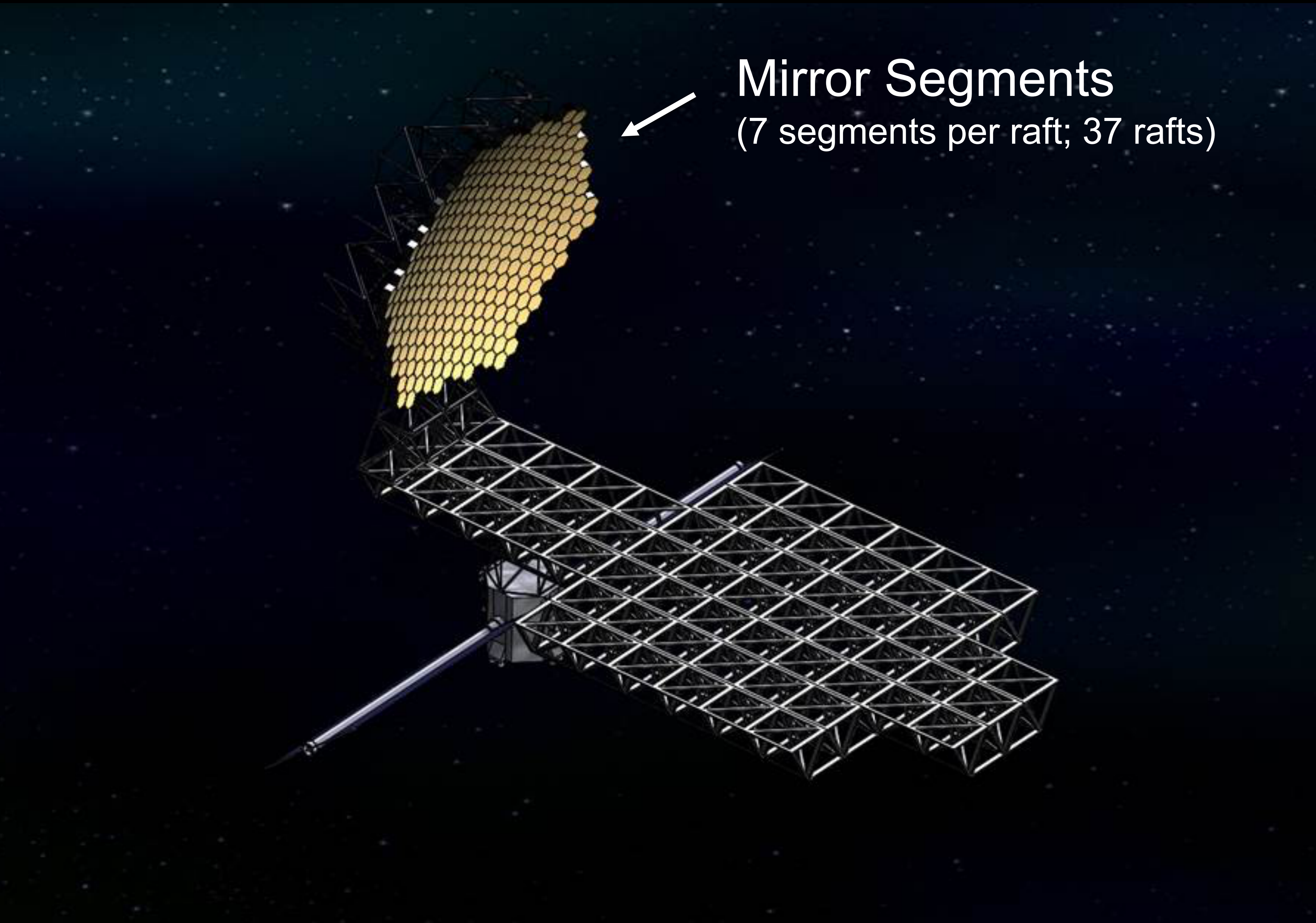
# Telescope Bus and Solar Arrays

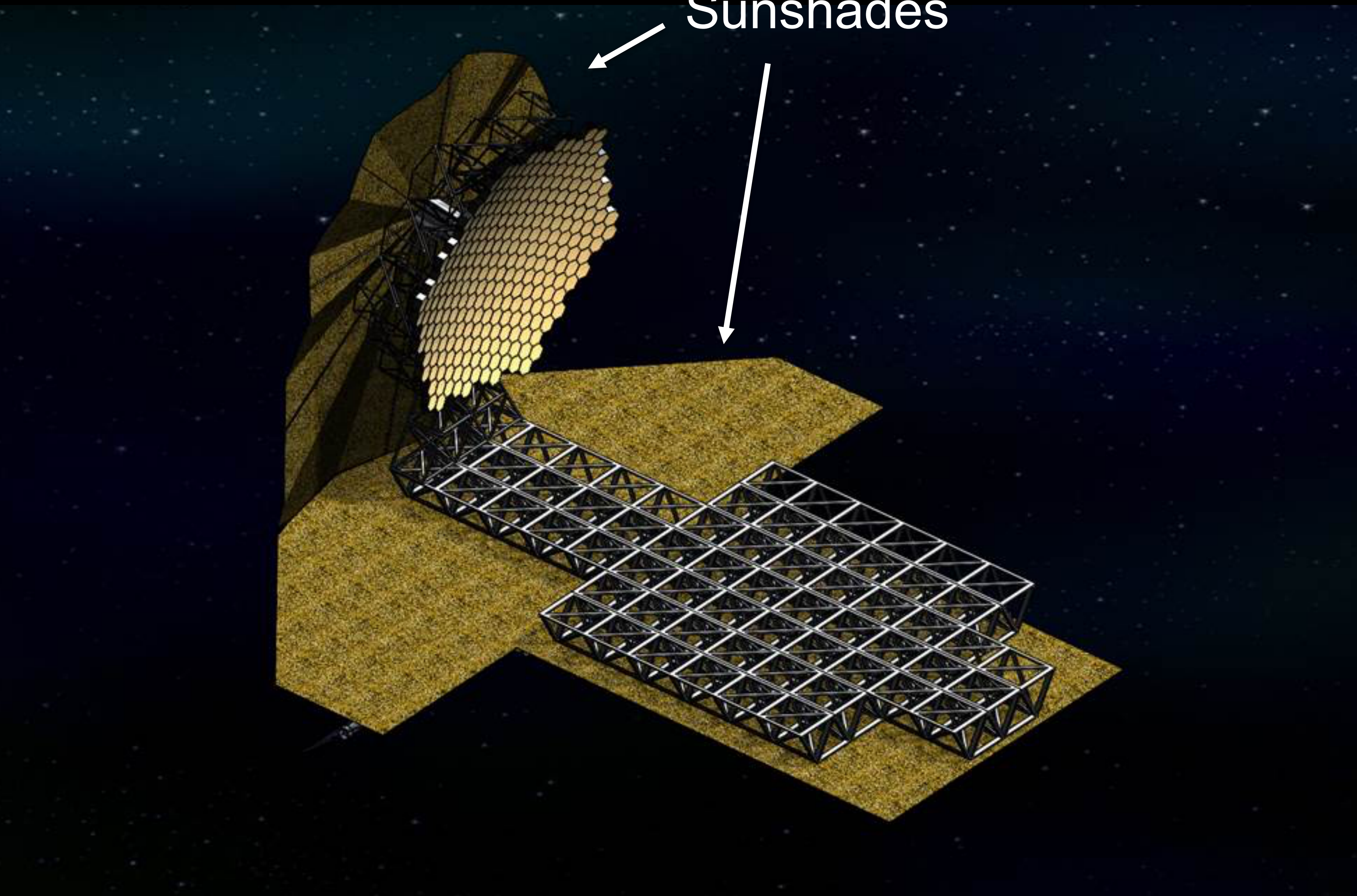


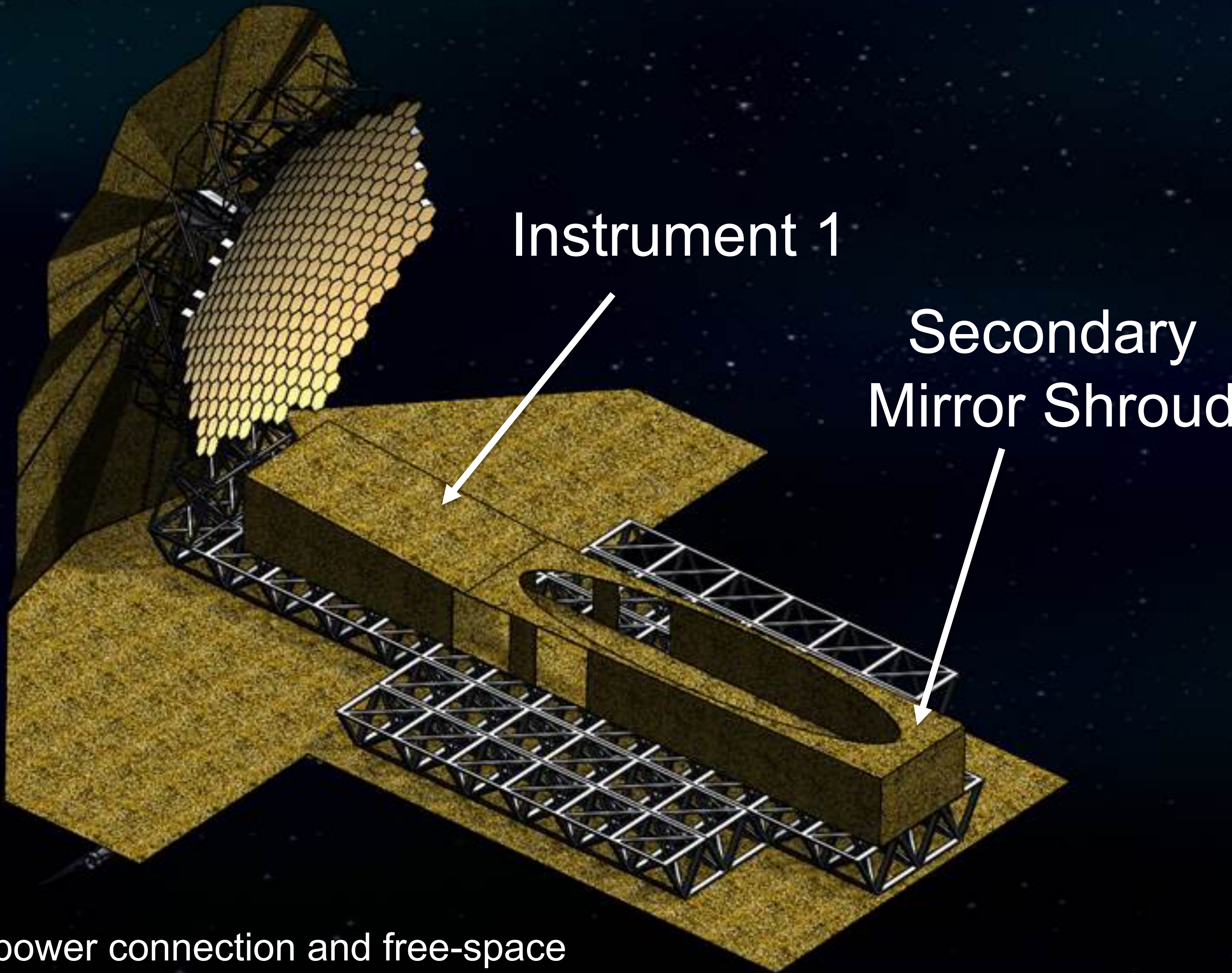
# Telescope Deployed Trusses



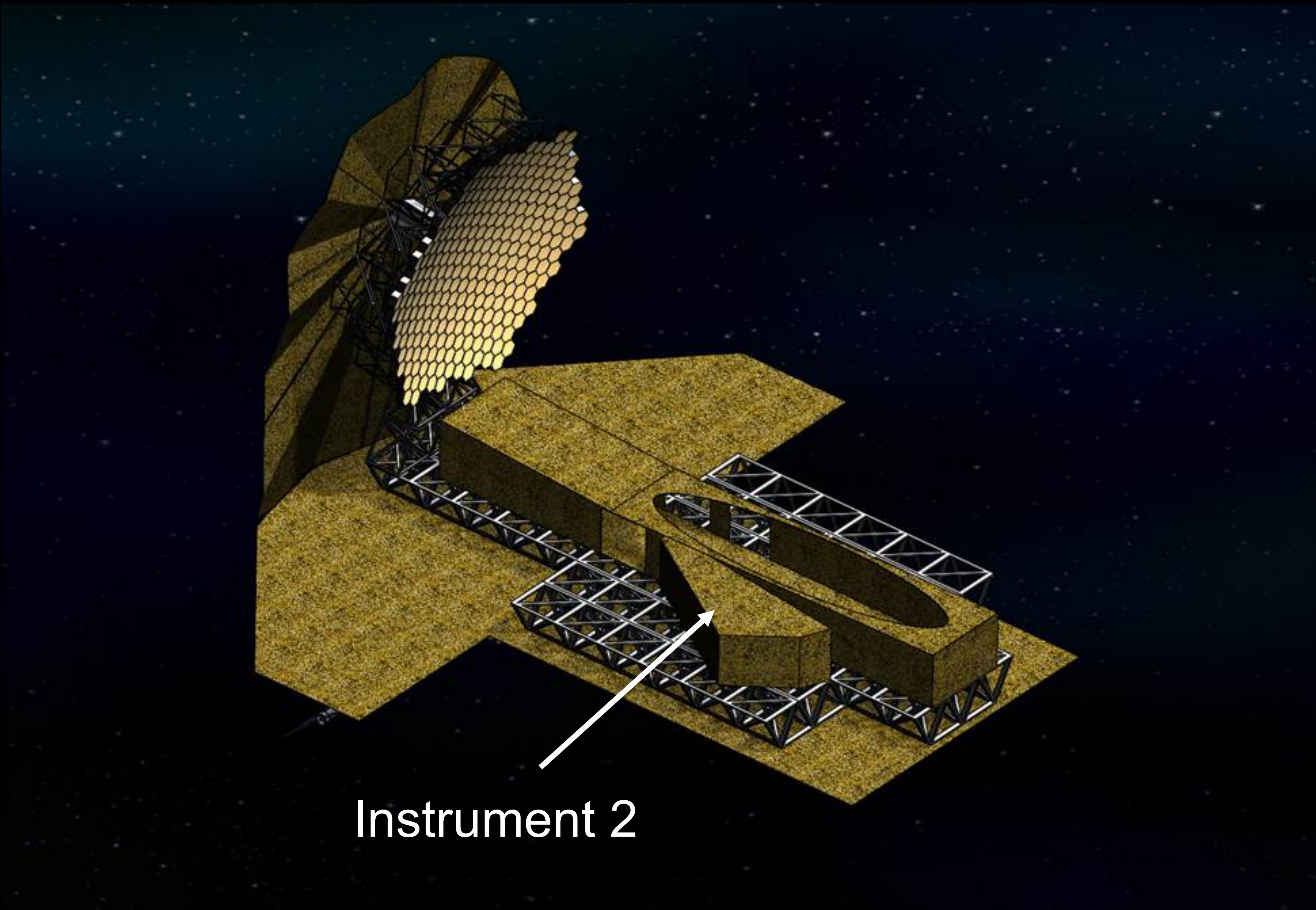

Backplane Trusses

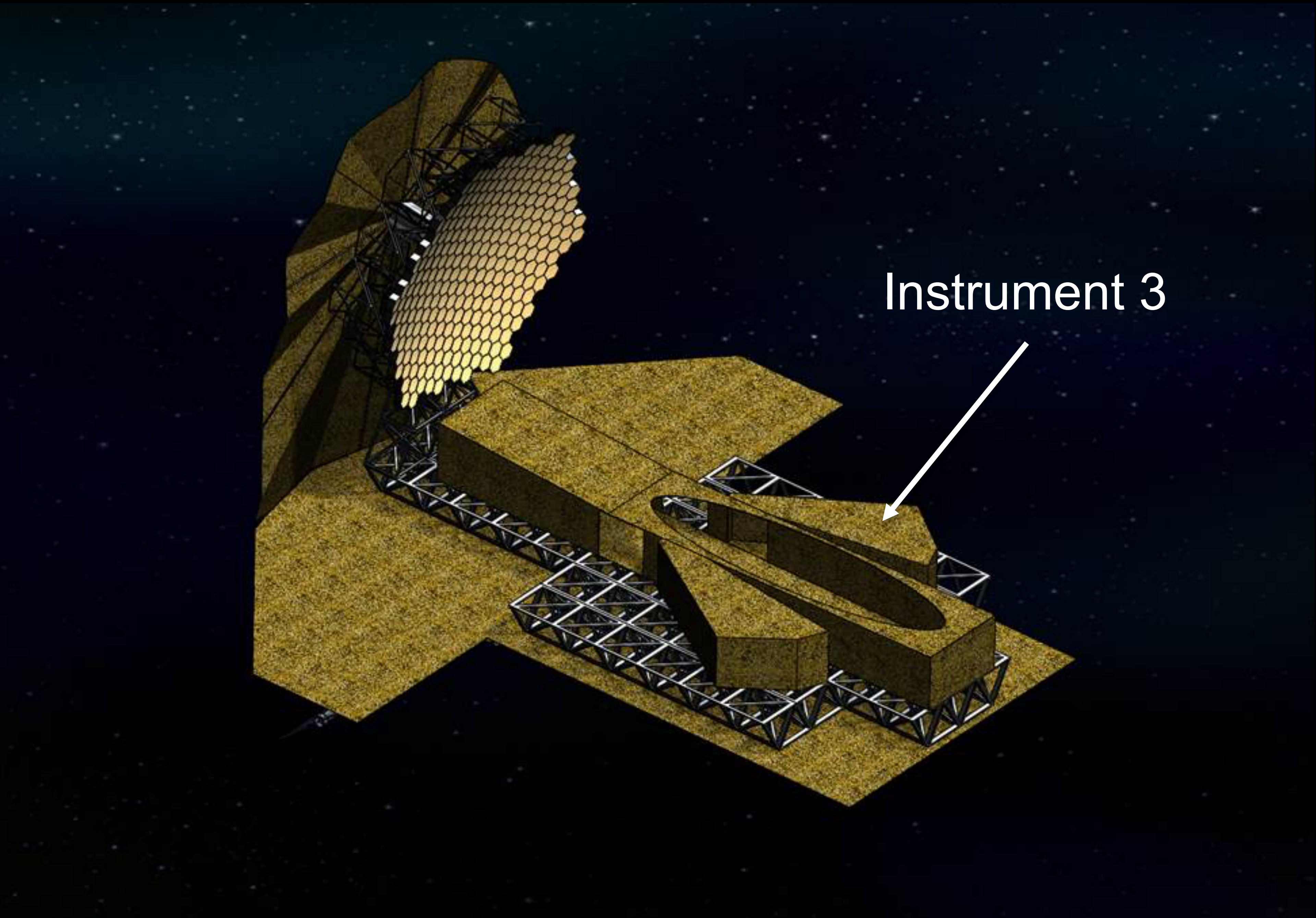

Mirror Segments
(7 segments per raft; 37 rafts)

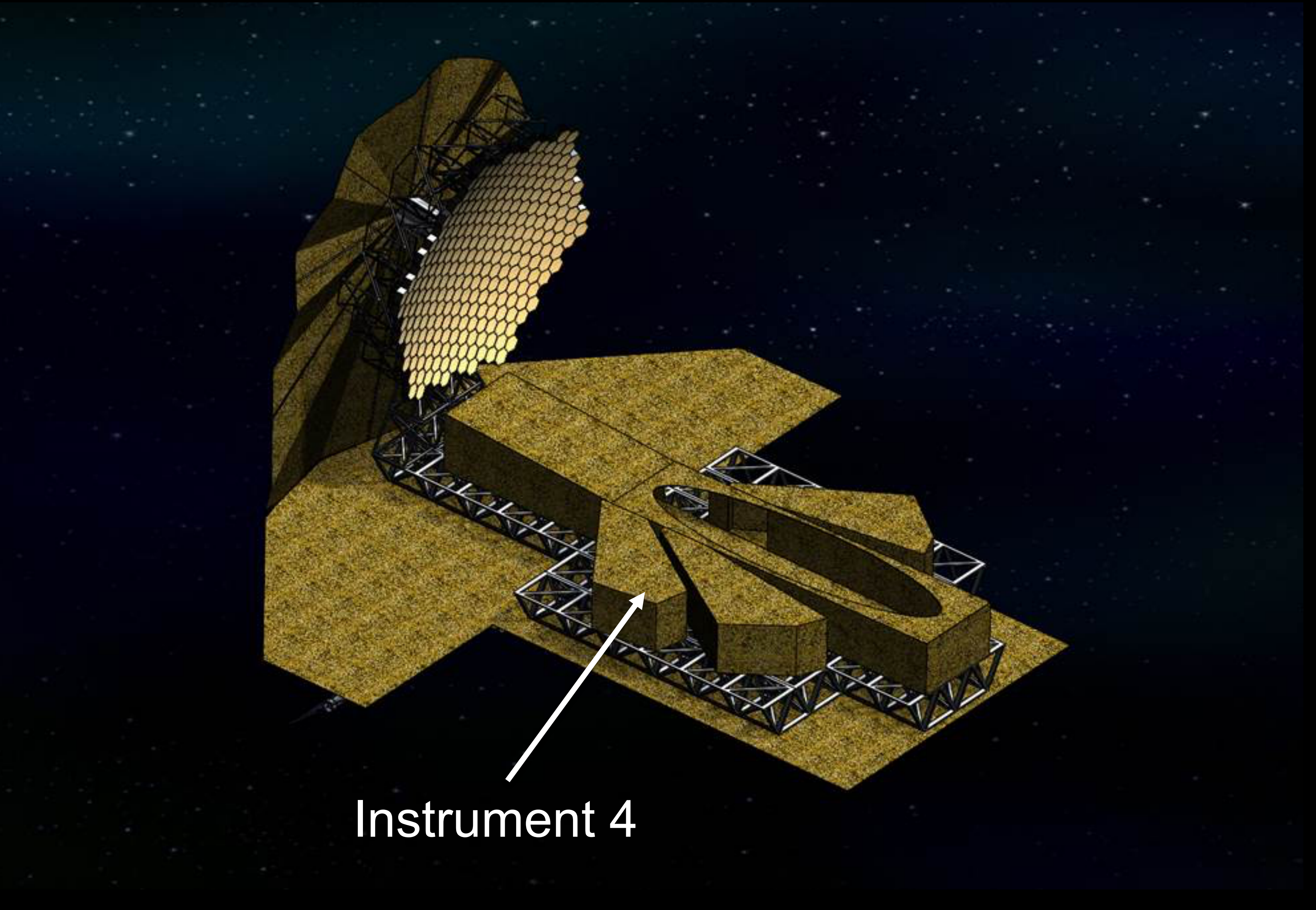

Sunshades

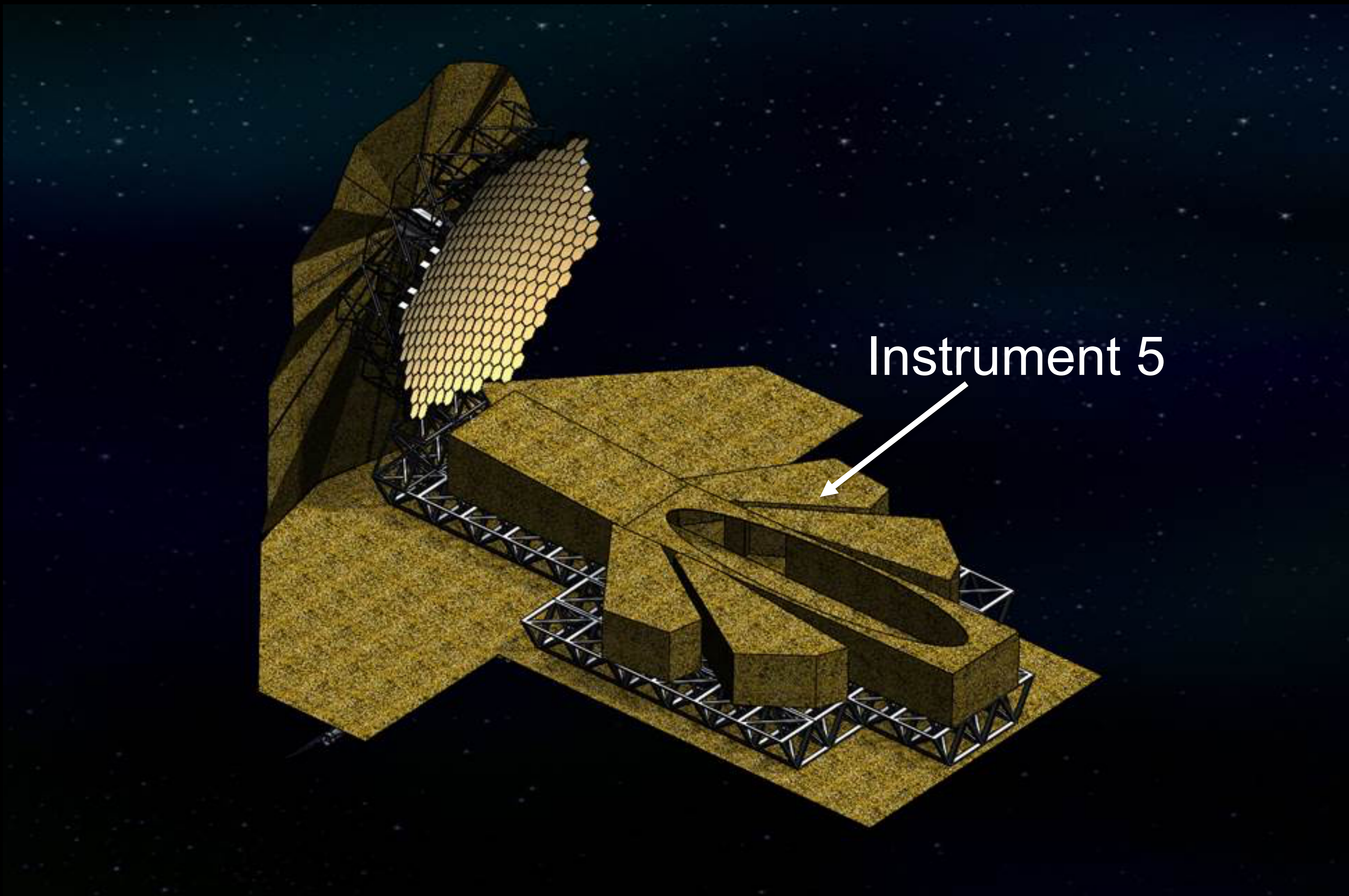



Simple power connection and free-space optical communications across short gap using a standard interface for all modules

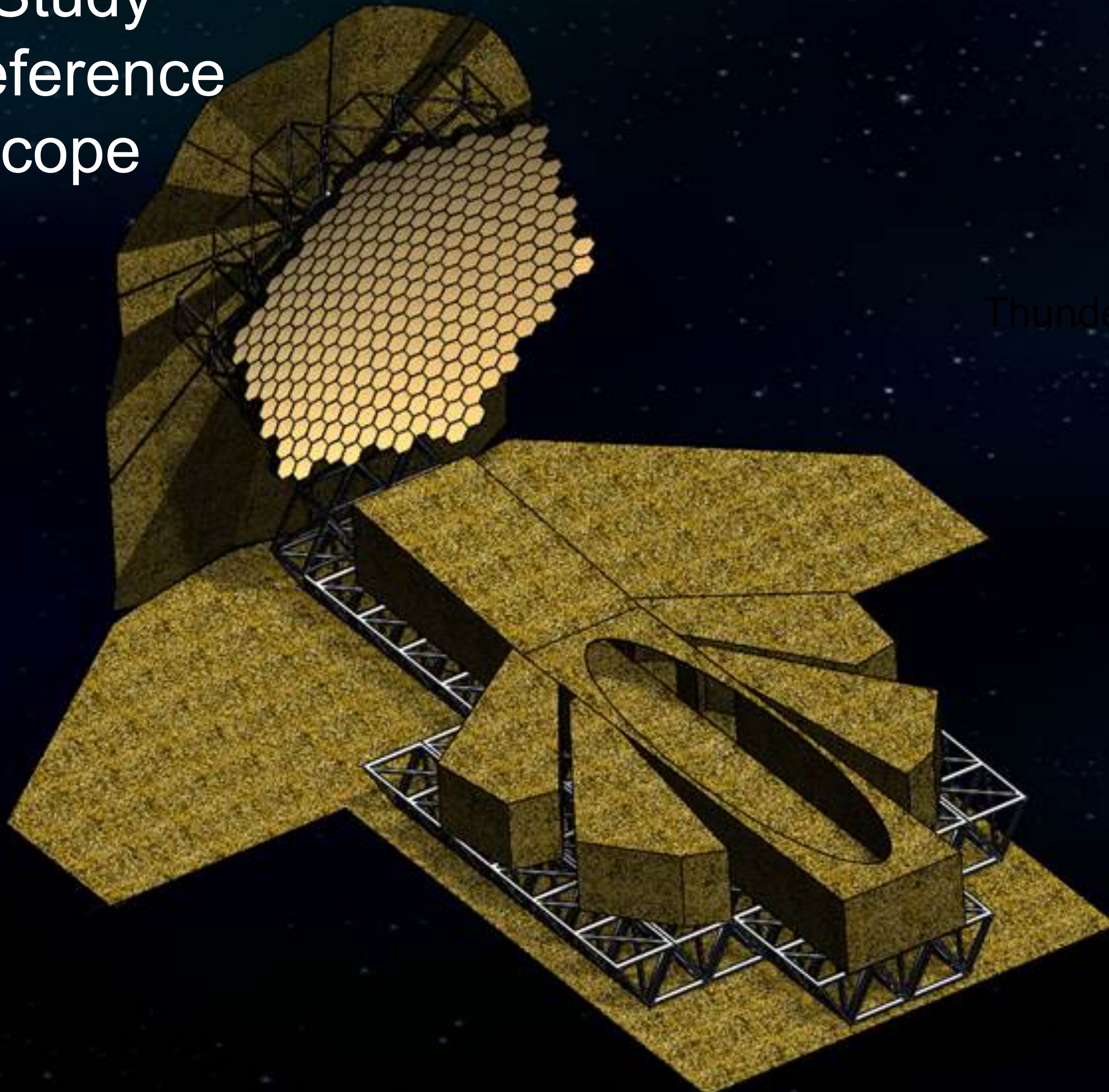

Instrument 2


Instrument 3


Instrument 4


Instrument 5

# iSAT Study 20 m Reference Telescope

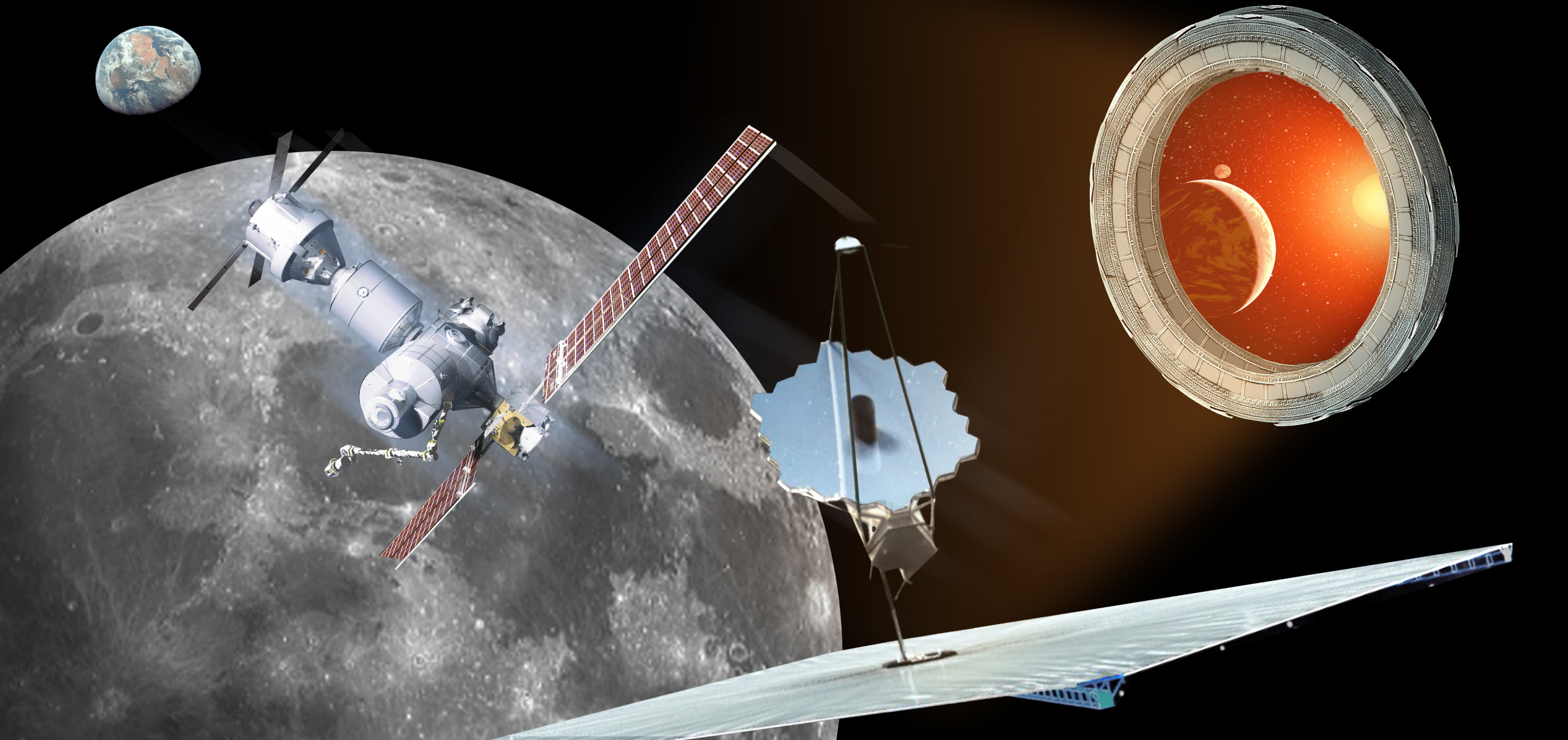


# Some Interim Results

- **The key design features that make iSA realizable are:**
  - (1) Modularized flight elements, (2) multiple LVs, (3) iSA
- **Many technologies already in hand, dev needed in a few areas**
  - in-Space Servicing (iSS) in particular to gain the benefits of serviceability
- **Unequivocal science benefits through serviceability**
  - Extended science for potentially decades through refueling, repairs
  - Swapping out instruments with newer ones without needing a new facility
  - Amortizing system costs over a longer science operational time
- **Risk mitigation benefits of iSA are compelling**
  - Architectures that eliminate or simplify dependence upon complex autonomous deployables (lower number of SPFs).
  - Recovery from flight system and assembly/deployment failures and anomalies.
  - Launch failure is not mission failure.
- **Modularization enhances domestic and int'l partnerships**.
- **Presents a path towards scalability**
- **Cost impacts are in process - uppers and downers**

iSA can play a major part of the astrophysics landscape in the next decade.

Stay tuned for final report in July.



# Additional Slides

# Capability Need Prioritization Results

| Capability | RANK | Aggregate Prioritization Score |
|---|---|---|
| 7.3 Fail-safe modes of behavior on failure detection | 1 | 1.00 |
| 10.3 Modular design | 2 | 0.96 |
| 14.1 Soft docking / berthing of modules | 3 | 0.91 |
| 13.1 A limited number of standard mechanical, electrical, thermal, and fluid connection approaches with well-characterized properties | 4 | 0.89 |
| 6.1 Standard protocols and ports to accommodate visiting vehicles and communication traffic | 5 | 0.87 |
| 5.1 Means of verifying the continuity of interface connections / disconnections | 6 | 0.84 |
| 10.5 Design for serviceability | 7 | 0.84 |
| 5.5 Modeling and simulation for verification and validation | 8 | 0.83 |
| 5.6 Modeling and simulation for assembly sequencing / planning | 8 | 0.83 |
| 4.1 Ability to reversibly assemble structural, electrical, and fluid connections | 10 | 0.82 |
| 6.2 Standard but secure communication protocols to accommodate interaction with other (TBD) associated systems | 11 | 0.80 |
| 5.7 Quantitative performance prediction for autonomous systems | 12 | 0.79 |
| 10.4 Design for assembly | 13 | 0.78 |
| 2.5 Ability to assemble high stiffness structures | 14 | 0.78 |
| 8.2 Known precision limits of any and all assembly agent elements across the assembly site's environmental envelope | 15 | 0.77 |
| 2.1 Robotic assembly with joining | 16 | 0.76 |
| 3.1 Ability to route electrical power and data across assembled joints | 17 | 0.76 |
| 4.2 Ability to disconnect structural, electrical, and fluid connections without propagating damage to other system components | 18 | 0.73 |
| 3.3 Ability to route fiber optical conductors across joints | 19 | 0.71 |
| 7.1 Intelligence to make stereotyped decisions correctly without human input. | 20 | 0.68 |